# Monte Carlo and Approximate Albedo Estimates for Tropical Convective Clouds as perceived by MISR

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## 1. Introduction

An area of radiative transfer that has not yet achieved closure is the realistic yet computationally-feasible modeling of the radiative effects of broken clouds. To date, the independent pixel approximation (IPA; Cahalan et al., 1994) has been shown to accurately represent the domain-average fluxes of not only stratocumulus clouds, but also of statistically-representative samples of small marine tropical cumuli (Benner and Evans, 2001; Evans et al., 2001). In the study here, we extend the investigation to a cloud type with even more optical and geometrical variability, that of tropical convection occurring under more convectively-favorable conditions. For these clouds, the tilted independent pixel approximation (TIPA) of Varnai and Davies (1999) should more closely capture the domain-averaged albedo at low Sun (e.g., Zuidema and Evans, 1999). TIPA requires more input information than IPA, however, making it more difficult to implement.

How well do IPA and TIPA perform on more complicated cloud types ?
Can a simple additional parameterization improve their correspondence to Monte Carlo results ?

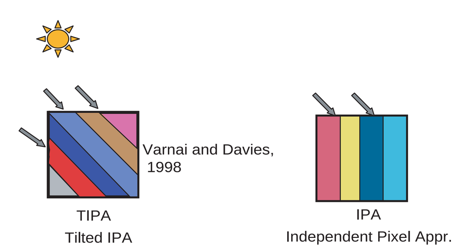
These questions are addressed here in a preliminary study using 10 cases from the MISR dataset.

## 2. Cloud Height Description/Data

The data come from the Multiangle Imaging SpectroRadiometer (Diner et al., 1999) instrument on the Terra spacecraft. It has 9 cameras at different viewing angles, 3 visible channels and one near-infrared. One MISR product is an operational stereo retrieval of cloud height, utilized here, and cloud winds. Cloud heights are at 1.1 km spatial resolution and about 500 m vertical resolution. The cloud heights of the selected cases are reasonable, but need to be validated further.

## 3. Monte Carlo model, TIPA, IPA

The spectral Monte Carlo (MC) model used has been adapted from that of Davies (1978). The model assumes conservative scattering, a Lambertian underlying surface and Mie scattering by either ice or liquid, depending on cloud height. The TIPA and IPA are implemented. These approximations treat clouds as optical depth distributions, either as vertical columns (IPA) or along the slant path of the Sun, thereby taking the cloud side into account (TIPA). No photon exchange occurs between the designated optical paths, so that plane-parallel RT theory can be readily applied. The two approximations are described visually below.




## 4. Orbit/Case Selection

We looked for clouds over open ocean with significant structure yet completely confined within about a 50 km by 50 km domain. This domain size allows for conclusions relevant at GCM scales and for the periodic boundary conditions within the MC code. Such a cloud type is typical of recent tropical convection. The selected cases come from near the maritime continent, where active convection can be expected even at the normally convectively quiescent 10:30 AM LT Terra orbit (e.g., Zuidema, 2002). Two orbits, occurring on Sept. 28 and Sept. 30, 2001, contribute the ten cases analyzed here. Latitudes and longitudes are as indicated on the figures below.

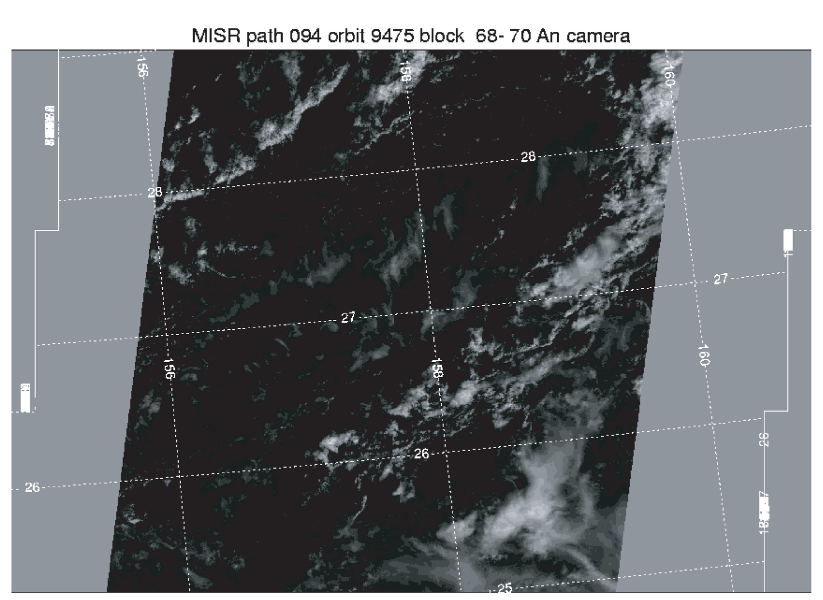



Fig1a: Nadir Radiances, Sept. 28, 2001

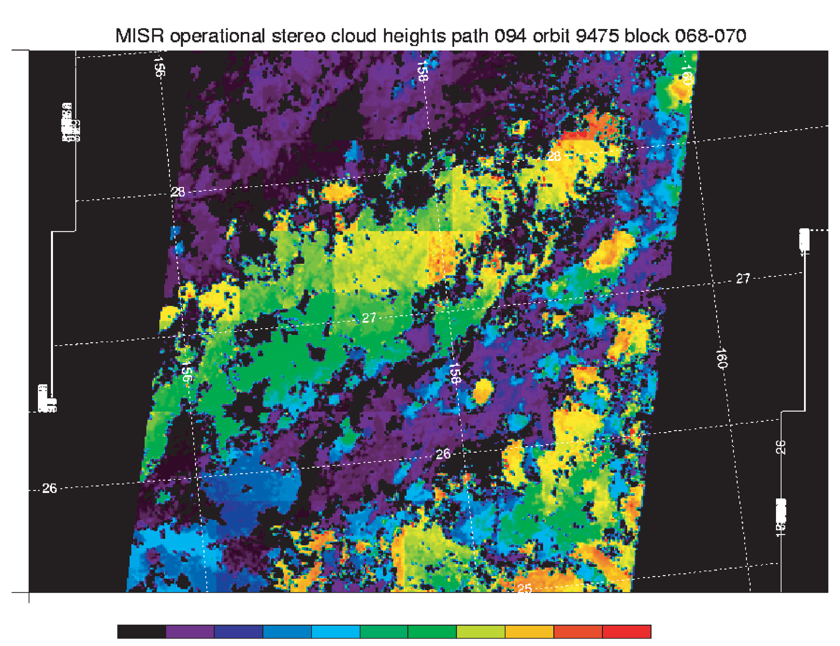



Fig 1b: Operational Stereo Heights, Sept. 28, 2001

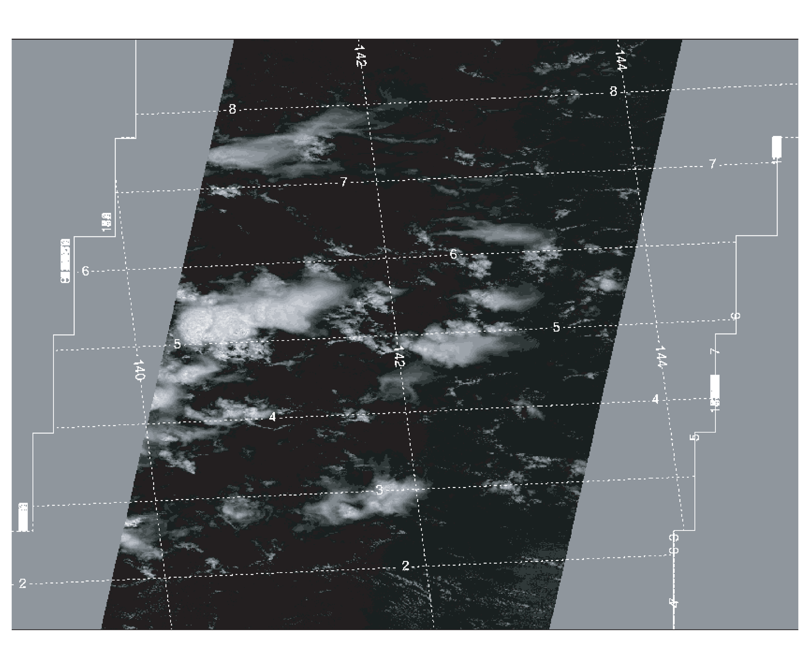


Fig 2a: Nadir Radiances, Sept. 30, 2001

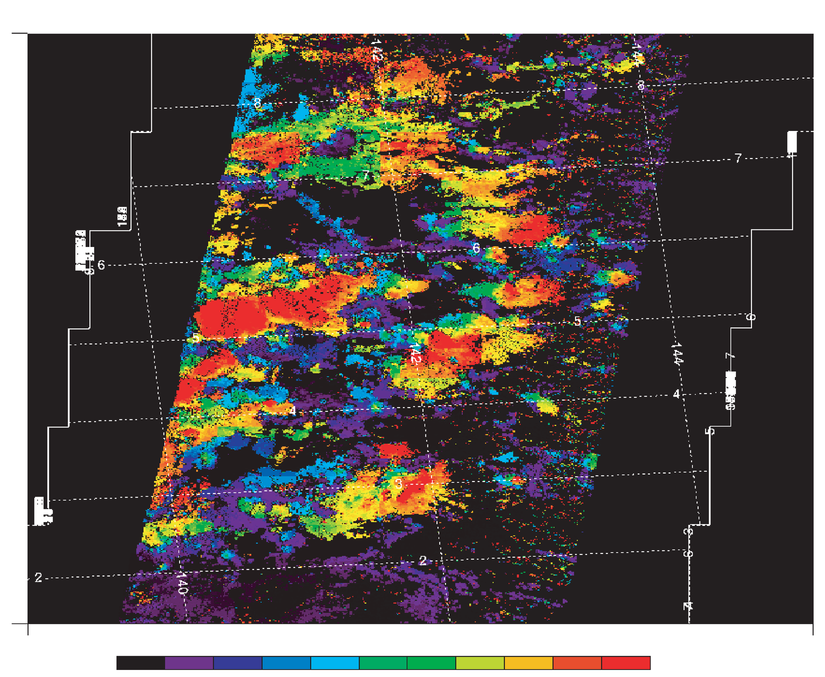



Fig 2b: Operational stereo Heights, Sept. 30, 2001

## 5. Cloud Optical Depth Estimate/Case Examples

Cloud optical depths are estimated from the 0.67 micron nadir reflectances, at a spatial resolution of 275 m. The most limiting assumption made is the use of plane-parallel theory for the optical depth estimate. We use the Streamer model (Key, 2001) and construct lookup tables specific to the conditions of each case. Clouds are partitioned into liquid and ice, where clouds w/ tops at 5.5 km or below are treated as all liquid, clouds with tops at 11 km and higher as all ice, and clouds with intermediate cloud top heights as a mixture of water and ice. Water and ice droplet sizes of 10 and 30 microns are assumed, along with a spherical ice habit. Fresnel reflection off the ocean surface is accounted for, as well as gaseous absorption and Rayleigh scattering. Three examples are shown below. From the optical depth and cloud height, a three-dimensional extinction field is constructed through assuming a cloud base at 500 m and a minimum extinction value of 25 1/km (so that thin upper-level cirrus retain a high cloud base).

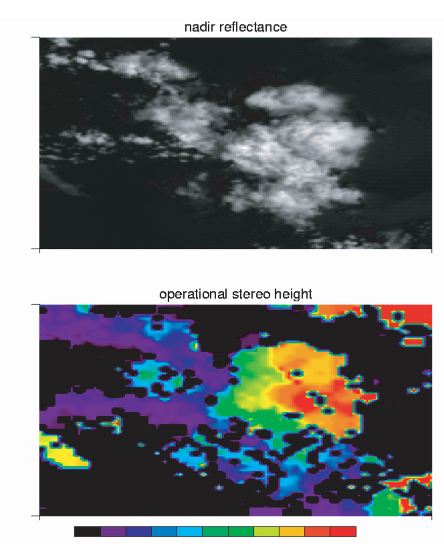



Fig.3a and b: Nadir Reflectances (top), stereo height (bottom) for case 10.

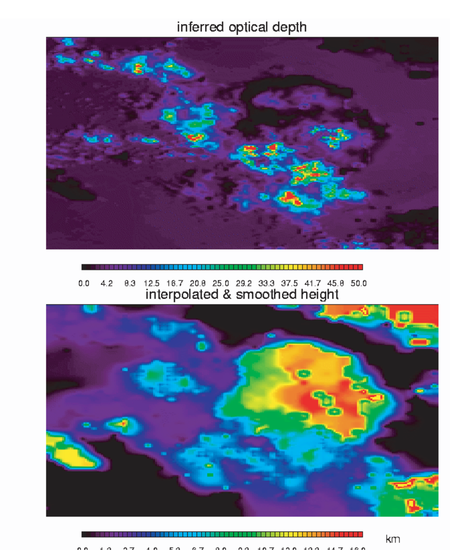



Fig. 4a and b: Retrieved optical depth, and finalized height field for case 10.

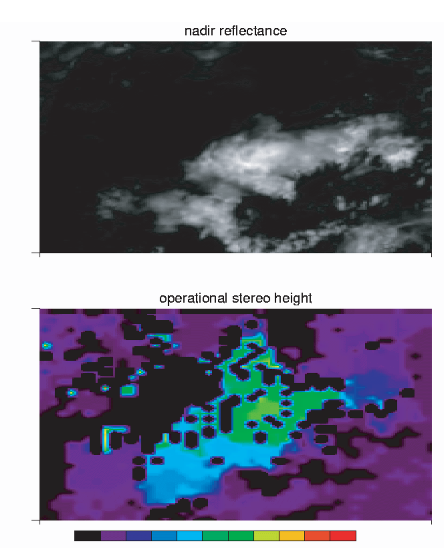



Fig. 5a andb: same as above but for case 3.

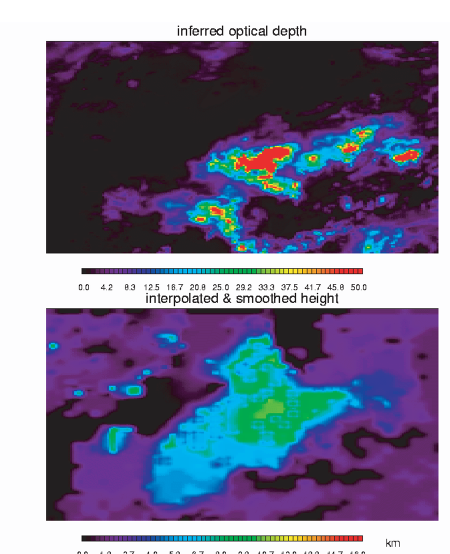



Fig. 6a and b: same as Fig 4 but for case 3.

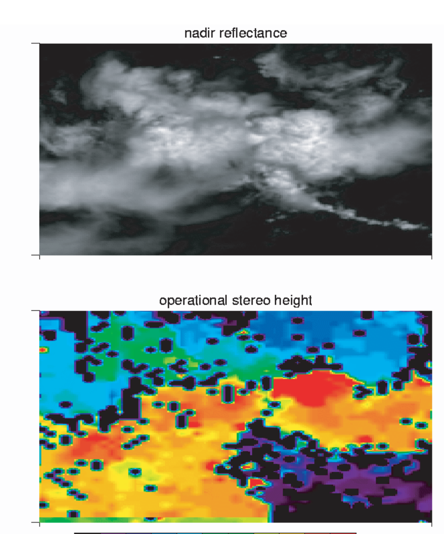



Fig. 7a and b: same as Fig. 3 but for case 8.

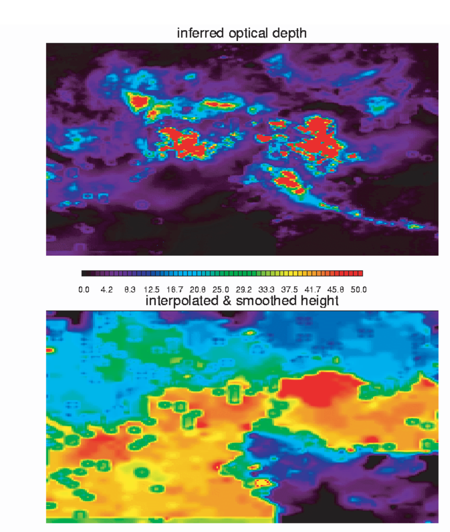



Fig. 8a and b: same as Fig. 4 but for case 8.

## 6. RESULTS:

### 6a: How well do TIPA and IPA perform ?

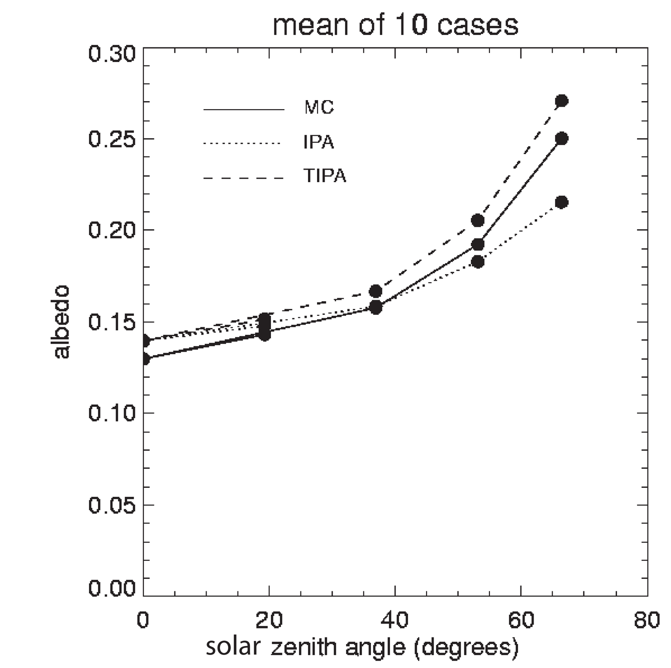



Fig. 9: 10-case mean Monte Carlo, IPA, and TIPA spectral albedos

Calculations are done at the data solar zenith angle and 5 other angles: cosine(solar zenith angle)=1.0, 0.8,0.6,0.4,0.2. The largest disagreement occurs when the Sun is low in the Sky. In the 10-case-mean shown above, TIPA overestimates by 8% at most, and IPA underestimates by 14% at most. For some of the individual cases, the disagreement is worse (see Fig. 10). IPA underestimates because it neglects the cloud side contribution, and TIPA overestimates because it neglects horizontal photon transport that ultimately eases downward photon movement.

### 6b: How does the magnitude of individual disagreements depend on underlying cloud properties ( $\tau$ and h) ?

The cases with the largest disagreements between the Monte Carlo and the approximate albedos, are those clouds possessing a larger fraction of high optical depths (see Fig. 11) preferably at high cloud heights (height distribution not shown). The highest correlation between (MC-IPA), (MC-TIPA) albedo differences is to the cloud height of optically-thicker clouds (r=-0.72 and r=0.89 respectively, for clouds with $\tau$ > 20), as shown in Fig. 12

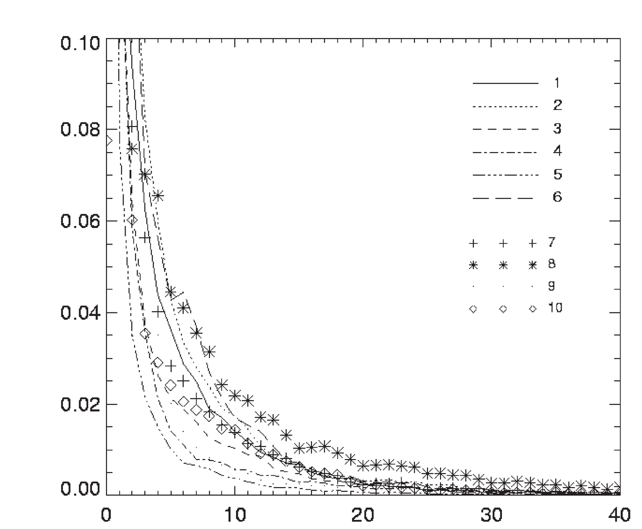



Fig. 11: Optical depth distribution for each case as a fraction; optical depths above 40 not shown.

## 7. Conclusions

The Monte Carlo (MC) domain-averaged albedos of 10 cases representative of active tropical convection were compared to the albedos calculated using the Independent Pixel Approximation (IPA), and the Tilted Independent Pixel Approximation (TIPA). TIPA performs somewhat better than IPA at low Sun, and correlates slightly better to an easily-measured cloud property: the cloud height or cloud thickness of optically-thick clouds. The IPA albedo is easier to calculate, however, and its departure from MC results could possibly be easily parameterized (see Fig. 12). Cloud fraction was not found to be a useful quantity because it was always high. Aside from examining more cases, a validation of the cloud heights needs to be performed, broadband rather than spectral albedo values would be more useful.

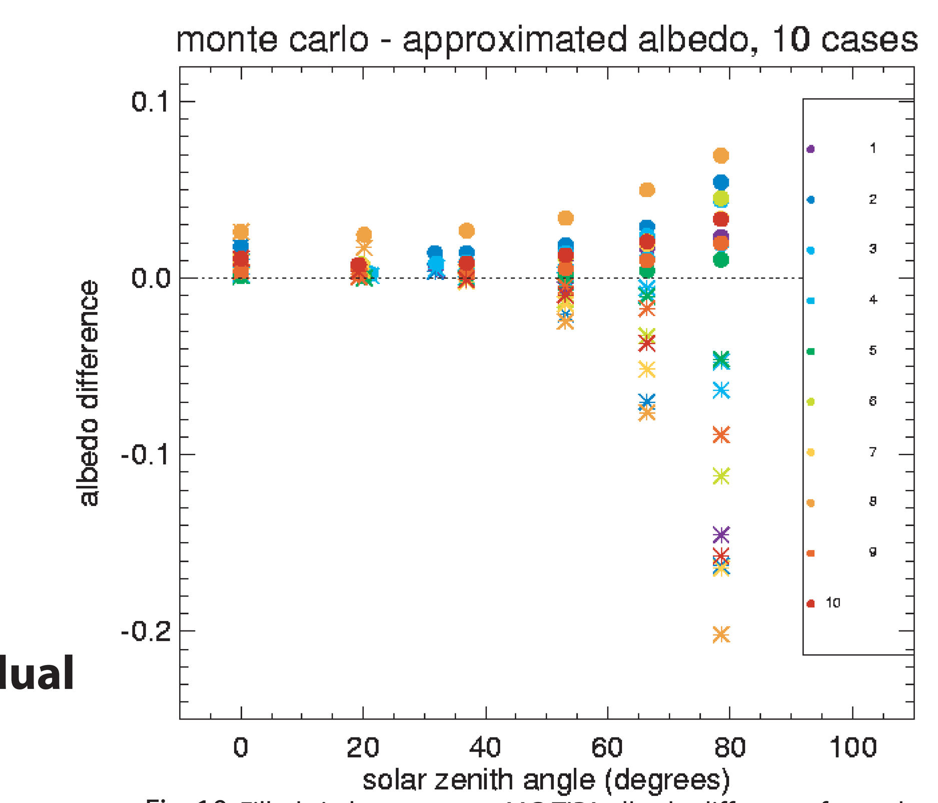



Fig. 10: Filled circles represent MC-TIPA albedo difference for each case, and asterisks represent MC-IPA albedo difference for each case. Colors correspond to the case number indicated in key.

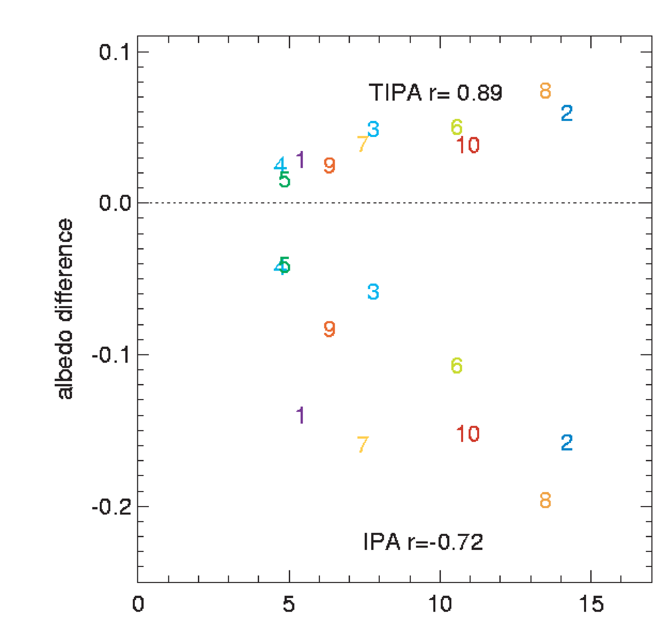



Fig. 12: Difference between Monte Carlo domain-averaged spectral and IPA (below dotted line)& TIPA (above dotted line) albedo, vs. cloud height, for those cloudy pixels with optical depths > 20.0. Numbered by case, color corresponds to the color used in Fig. 10. Note that cloud thickness=cloud height - 500m for these pixels.

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